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GLACIATION IN THE TELLURIDE QUADRANGLE, COLORADO

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OUTLINE

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- Literature Concerning Glaciation in This and Adjacent Quadrangles
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PART II

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- Summary and Conclusions
  - Topographic Effects of Glaciation
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    - Hanging Valleys
    - Rounded Topographic Forms
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    - Terraces and Valley Trains

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[1] This paper presents primarily the results of work done by the author in the field seasons of 1904 and 1905, under the direction of Professor R. D. Salisbury. Acknowledgments are due, besides, to many observers who have done work in the same region, particularly to Mr. Whitman Cross, who has for some years been in charge of the general geological investigations in the San Juan Mountains, to Mr. L. L. Everly, who assumed equal responsibility with the author in the work of the first season, and to Mr. John T. Haworth, who rendered service as field assistant in the second season. —A. D. H.

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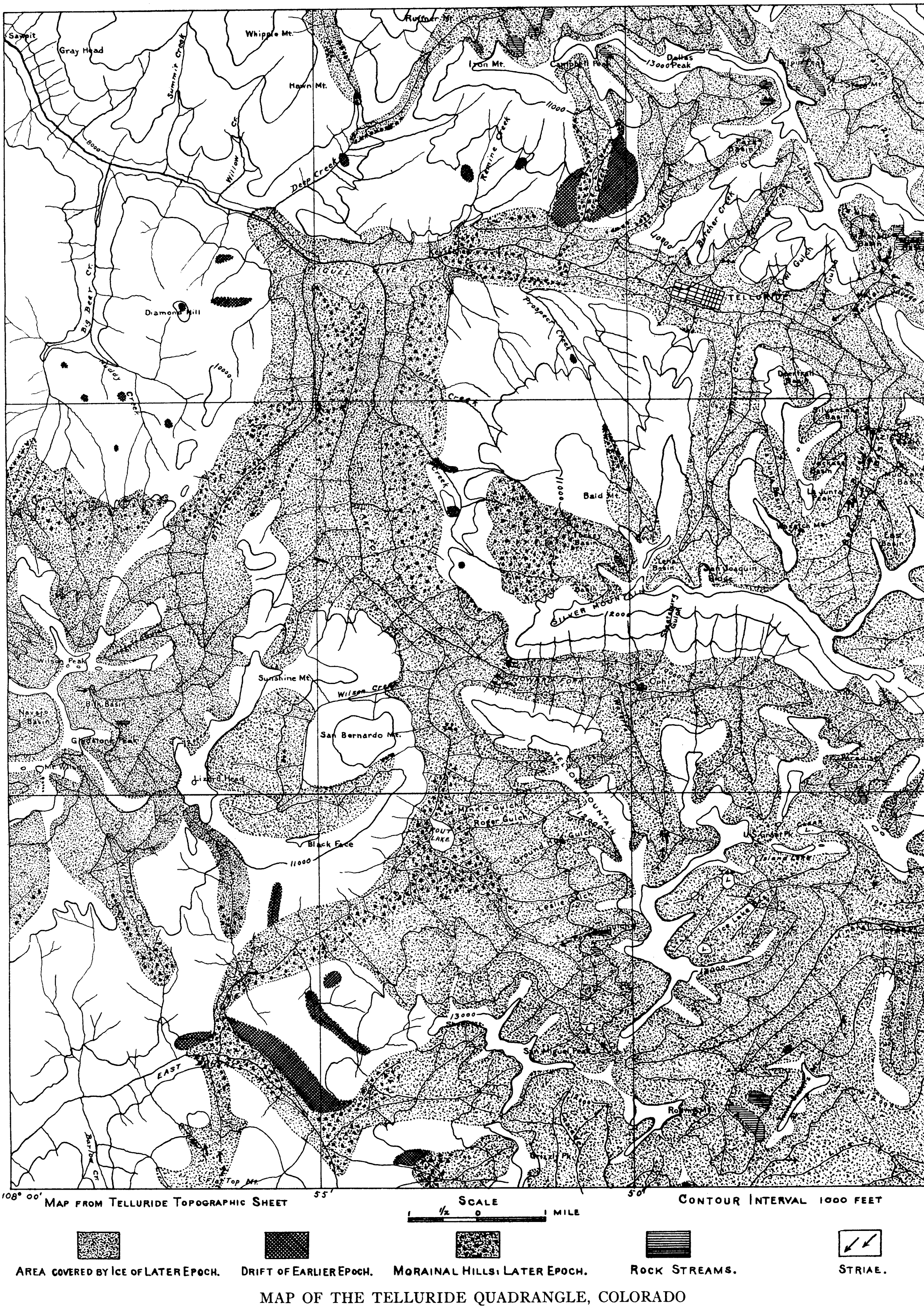

MAP OF THE TELLURIDE QUADRANGLE, COLORADO

Showing the distribution of glacial formations. Glacial geology by Allen D. Hole, in 1904 and 1905, under the direction of Rollin D. Salis

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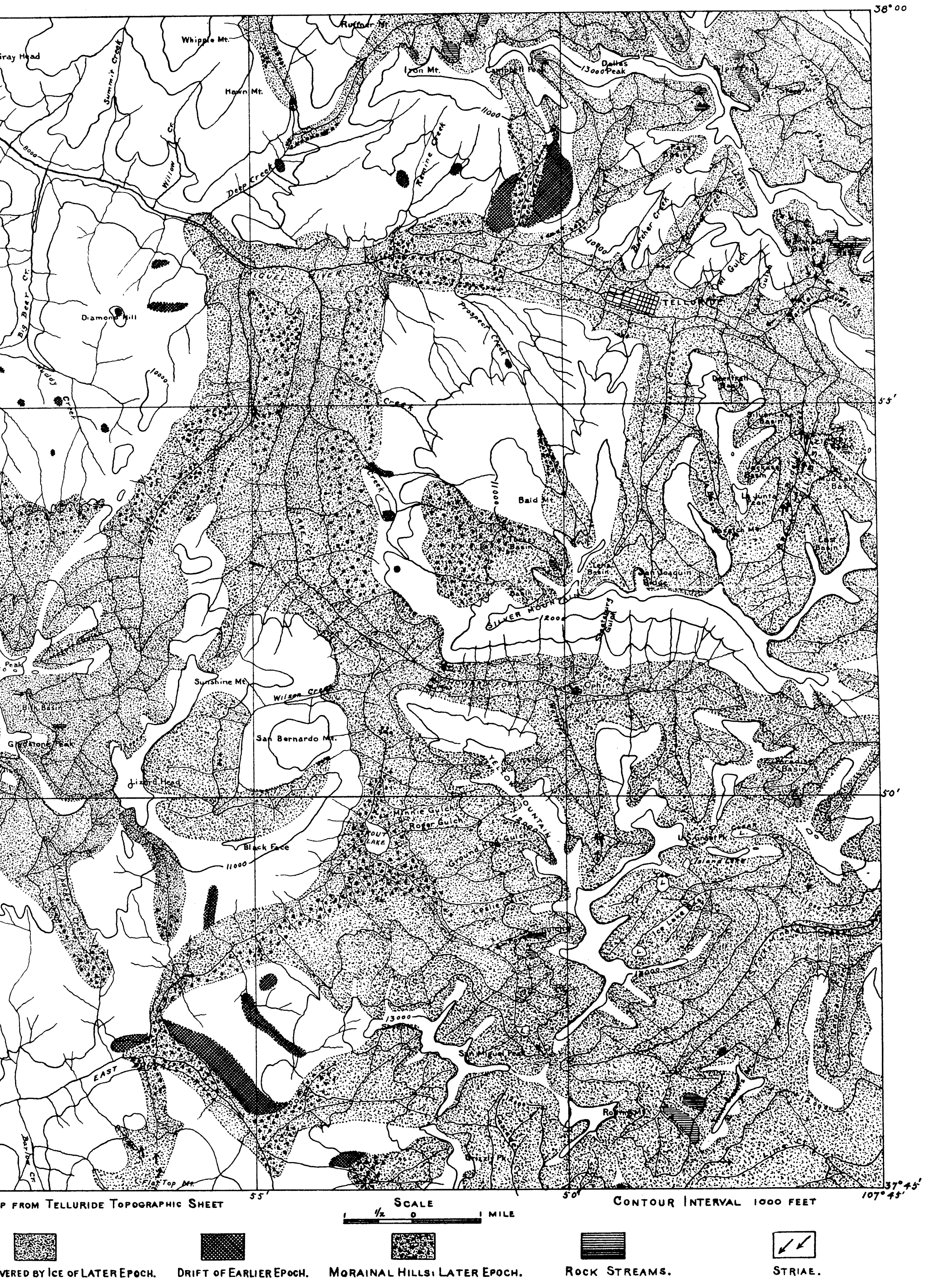

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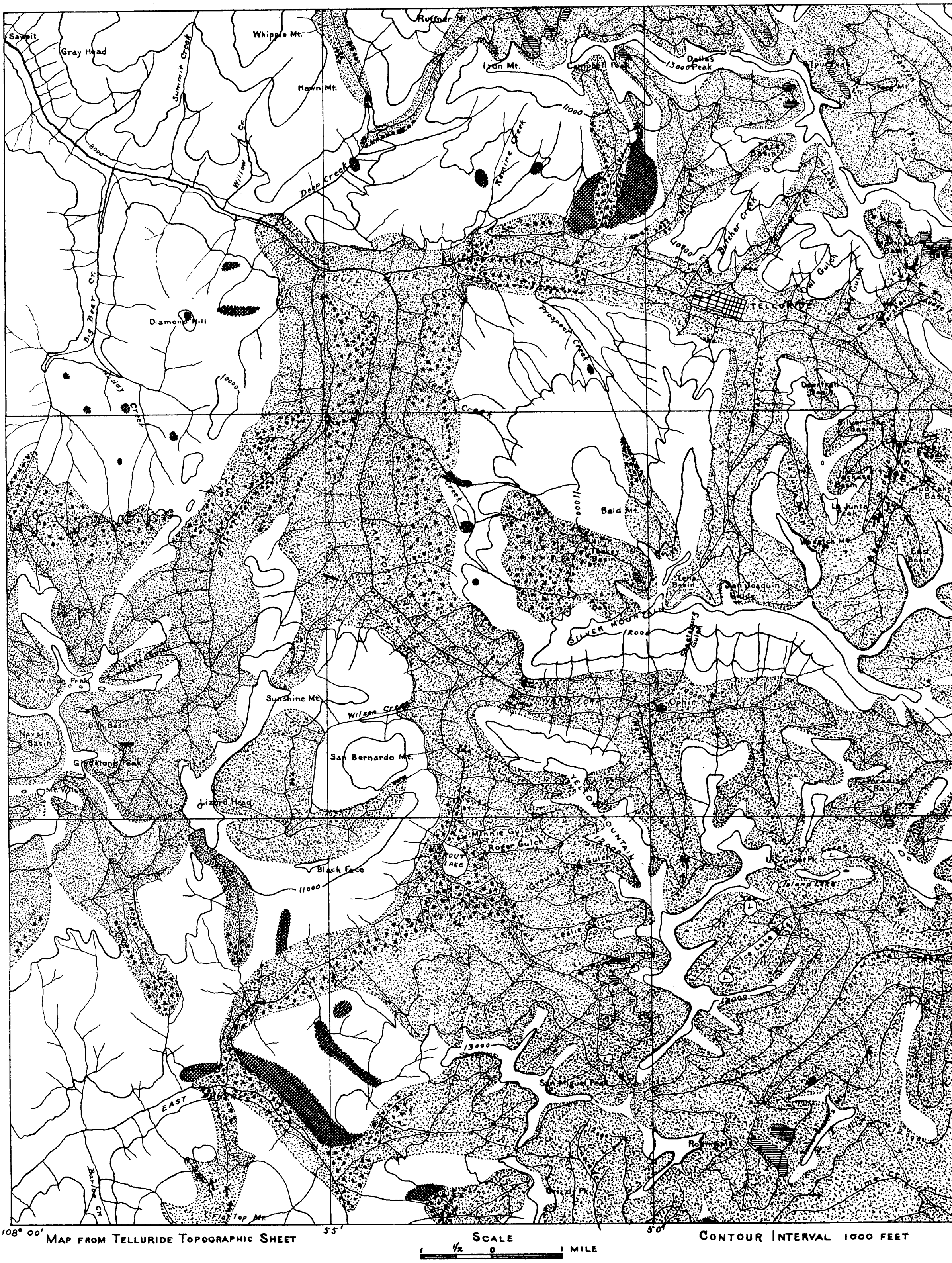

▨ AREA COVERED BY ICE OF LATER EPOCH.

▨ DRIFT OF EARLIER EPOCH.

▨ MORAINAL HILLS: LATER EPOCH.

▤ ROCK STREAMS.

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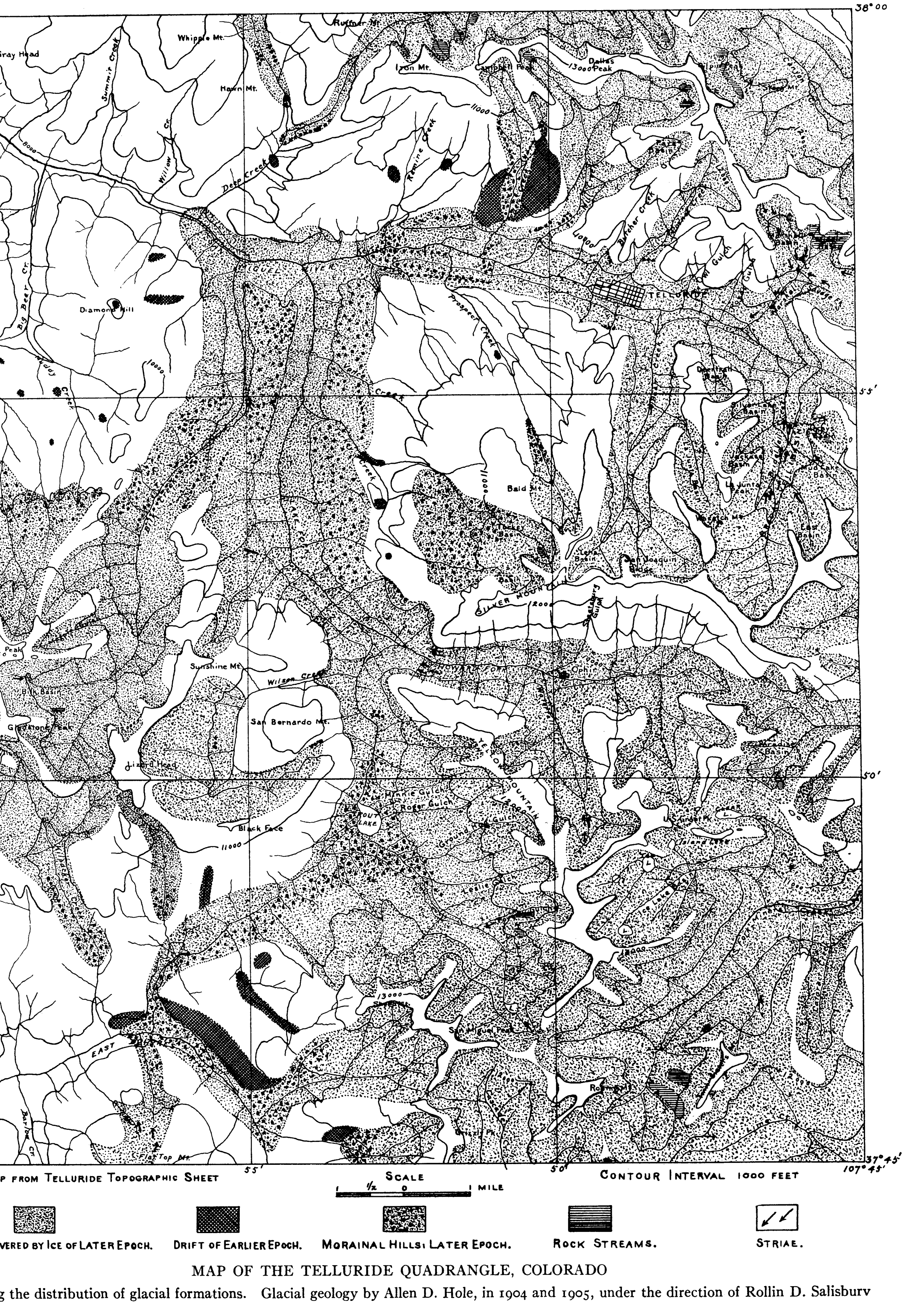

MAP OF THE TELLURIDE QUADRANGLE, COLORADO

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Characteristics of the Deposits of Drift of the Earlier and the Later Epochs
Extent of Glaciation
    In the More Recent Epoch
    In the Earlier Epoch or Epochs
Age of the Drift
    More Recent Epoch
    Earlier Epoch or Epochs
Post-glacial Changes
Glaciation as Affecting the Location of Mining Claims

PART I

LOCATION AND EXTENT OF AREA

The Telluride quadrangle, Colorado, lies in the southwestern part of the state about 60 miles from the western and 55 miles from the southern boundary. It is included between meridians 107° 45′ and 108° 0′ west longitude, and parallels 37° 45′ and 38° 0′ north latitude, having therefore a width of a little less than 14 miles, a length of a little more than 17 miles, and an area of over 235 square miles.

DRAINAGE

The greater part of the area of the quadrangle is drained by the San Miguel River, which flows northwest to join the Dolores, a tributary of Grand River; but the Uncompahgre River to the north, the Animas to the southeast, and headwaters of the Dolores to the southwest each receive some streams heading within this area; so that streams flow outward across the borders of the quadrangle toward practically all points of the compass, finally, however, to join their waters with those of the other tributaries of the Colorado River before reaching the sea.

TOPOGRAPHY

The chief topographic features of the quadrangle may be grouped under three heads, viz.:

1. The rugged peaks and ridges in the eastern half of the area, a part of the San Juan Mountains.

2. The isolated, loftier peaks of the Wilson group in the central part of the western half.

3. The plateau north and south of the Wilson group, cut by deep canyons in which flow the San Miguel, and the East Dolores rivers and their tributaries.

The highest point in the quadrangle is Mt. Wilson, near the western side, 14,250 feet above the sea; numerous peaks, however, in the eastern half rise above 13,500 feet, and ridges extend for miles with crests at an elevation greater than 13,000. The lowest point in the quadrangle is in the canyon of the San Miguel River, in the northwestern part, an elevation of 7,500 feet; but the plateau in which the canyon is cut has at most points an elevation of not less than 9,000 feet.

The topographic features as they exist today in the quadrangle are the result of agencies which have been in operation from a remote period in the history of the earth to the present time. The earlier include all those forces and processes which culminated in the relative elevation of the land thousands of feet above the sea, the ejection of enormous quantities of lava and other volcanic material, and the dissection of this elevated and ejected material by erosion, until, at the opening of Pleistocene time, the mountains, plateaus, and main stream channels must have had positions relatively much the same as they have now. The details of the topography, however, are due to agencies which have operated within Pleistocene and recent times; chief among these agencies which have produced results more or less well marked are: (1) agents of weathering, including freezing and other changes in temperature; (2) running water; (3) lakes and ponds; (4) moving masses of snow and ice, not glacial; (5) landslides; (6) glaciers.

GEOLOGICAL FORMATIONS

Observations in regard to the geology and topography of areas within this quadrangle have been made by a number of scientists, including members of the Hayden Survey and representatives of the War Department of the United States, as well as many others; the first detailed work to cover the entire area, however, was that undertaken by Mr. Whitman Cross and his associates, the results of which were published by the United States Geological Survey in the *Telluride Folio*, in 1899, from which the summary given below is largely taken.

Speaking generally, it may be said that so far as rocks near the surface are concerned, the plateau portion of the quadrangle is for the most part underlain by sedimentary formations, while the peaks and ridges in the mountainous portion are composed very largely of igneous rocks. Of the latter there are (1) various phases of intrusive bodies which in form include stocks, laccoliths, dikes, and sills, and in composition range from basalt to rhyolite, including andesite, gabbro-diorite, diorite-monzonite, diorite-porphyry, monzonite, and granite-porphyry; and (2) widespread sheets of bedded extrusive rocks of three series named in order from the oldest, the San Juan, the Silverton, and the Potosi rhyolitic series.

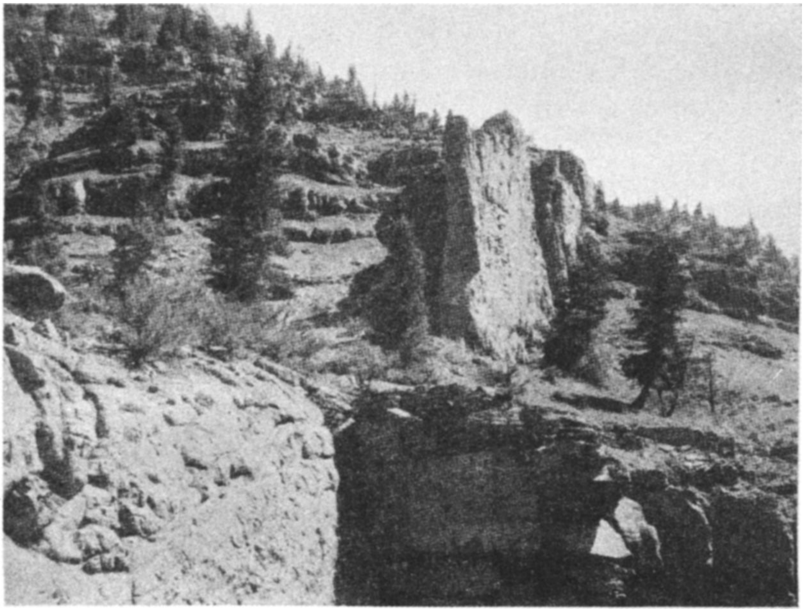

FIG. 1.—Dike in sandstone on the north side of the San Miguel River, one-fourth of a mile northeast of the mouth of Big Bear Creek. Looking northeast from a point 100 feet above the stream.

The intrusive bodies vary in size from dikes whose maximum thickness is to be expressed in feet and inches, and which at best have contributed only in the most insignificant degree to the physiographic and structural features of the region (Fig. 1) to stocks whose dimensions are to be expressed in miles, and which have given rise to many of the loftiest and most rugged peaks to be found within the area, as for example the Wilson group (Fig. 2) and Grizzly Peak.

With the exception of a few small outlying remnants, the bedded volcanic rocks are found only in the eastern half of the quadrangle where they form the lofty and rugged peaks and ridges of the San Juan mountain front. The lowest member, the San Juan series, consists of andesitic tuffs, breccias, and agglomerates, cemented to some extent by minerals such as calcite deposited by circulating waters, so that in favorable positions steep, clifflike slopes are formed. Its maximum thickness is 2,000 feet. The intermediate series, named, after the publication of the *Telluride Folio*, the Silverton series, consists of alternating andesitic and rhyolitic flows with which are mingled sheets of tuff and breccia of andesite and

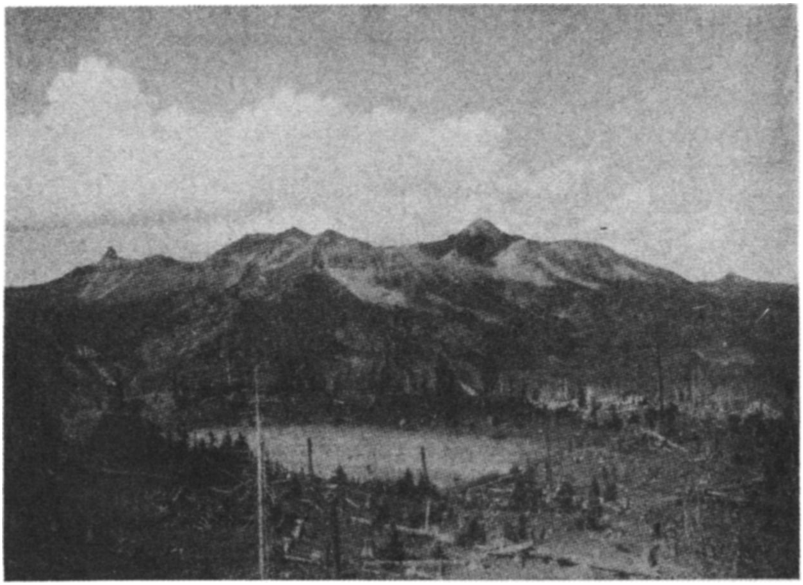

FIG. 2.—The Wilson group of mountains, an eroded stock. Looking south of west from elevation about 11,200 feet at the mouth of Alta basin. The body of water shown in the foreground is a small temporary glacial lake formed by unequal distribution of drift.

rhyolite, making up a maximum of 1,300 feet in thickness. This series results in topographic forms similar in some situations to those resulting from the erosion of the San Juan series, in others more closely resembling the steeper cliffs of the Potosi rhyolite. Of the upper, Potosi rhyolitic series, a maximum thickness of about 1,300 feet remains, consisting of a series of rhyolitic beds, the majority of which are flows, but some are tuffs. The area covered by this series in the quadrangle is comparatively very small, but topographically it is conspicuous, not only because it forms the summits of the highest peaks and ridges, but also because it weathers in remarkably steep cliff faces, showing often a vertical columnar structure, and where the direction or degree of the slope changes, bold, sharply angular outlines.

Below the bedded volcanic rocks in position there occur in order the following sedimentary strata, viz.: (1) the Telluride conglomerate, (2) Cretaceous shales and sandstones, (3) Jurassic shales, sandstones, and limestones, (4) Triassic sandstone and conglomerate, and (5) some sandstone and conglomerate probably of Permian age.[1]

These sedimentary rocks have influenced in various ways the course of events in the geological history of the quadrangle, and have been important factors in producing certain conspicuous topographic forms found there at present, as for example the steep walls of the canyon of the San Miguel River, due in many places to the presence of sandstones and conglomerates. For the most part these sedimentary strata retain their horizontal position except in certain cases in the immediate vicinity of bodies of intrusive volcanic rocks; one conspicuous monocline, however, is to be found west of the mountain front, and folds somewhat more complex in the southeastern corner of the quadrangle.

LITERATURE CONCERNING GLACIATION IN THIS AND ADJACENT QUADRANGLES

1877. The Hayden Geological Survey.—In Appendix A to the *Ninth Annual Report of the United States Geological and Geographical Survey of the Territories,* Dr. F. M. Endlich reports, under the heading "Ancient Glaciers in Southern

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[1] Cross, *Engineer Mountain Folio,* p. 7, and various other publications there referred to.

Colorado," pp. 216–26, evidences of glaciation at a number of points in the San Juan Mountains. These evidences include *roches moutonnées*, grooved and striated rock in place, shallow lakes, and glacial drift in the form both of scattered erratic bowlders and moraines. As to the time relations involved, Dr. Endlich concludes (1) that at least one glacier, called by him the Conejos, was not older than late Tertiary time, and might be much more recent, basing his conclusion on the relation of its action to the basaltic lava flows; and (2) that the glacier which descended the Animas valley was of older date than those whose effects were to be seen near the headwaters of the different streams named. He does not, however, seem to mean that there were two separate stages of glaciation. The total work done by glaciers in modifying the preglacial topography he considers to have been slight; aside from this no estimate is made as to the amount of glacial erosion, amount of ice, or area covered when the ice was at its maximum.

1883. R. C. Hills.—In the *Proceedings of the Colorado Scientific Society*, Vol. I, in an article entitled "Extinct Glaciers of the San Juan Mountains," pp. 39–46, Mr. Hills cites evidences of glaciation from numerous points, and makes certain estimates as to the extent of the ice and the time relations involved. The following summary shows the more important points presented:

1. The ice attained a greater thickness and covered an area many times more extensive on western than on eastern slopes.
2. Glaciers were not confined to existing valleys, but at some remote period probably the entire western slope of the mountains, except perhaps the higher peaks, was covered with an unbroken sheet of ice. As evidence supporting this conclusion he mentions (*a*) the presence of large granite bowlders distributed 5 miles west of Durango; (*b*) erratics of eruptive rocks on mesas flanking the San Miguel River 35 miles from the source of the river; and (*c*) erratic bowlders within a short distance of Montrose.
3. The Animas Glacier was 1,200 to 1,500 feet thick "between Elbert and Silverton," and nearly 3 miles wide "a short distance above Elbert."
4. During the period of extension of the ice sheet the erosion of Upper and Middle Cretaceous rocks amounted to 200 to 500 feet.
5. Box canyons 50 to 100 feet deep have been eroded since the retreat of the local glaciers as in the Uncompahgre valley at Ouray and in the Animas valley above Elbert, etc.
6. The total extent of the old ice envelope is estimated at more than 4,500 square miles.

1893. George H. Stone.—In Vol. I of the *Journal of Geology*, pp. 471–75, Mr. Stone describes glacial phenomena found in the valley of the Las Animas River, and in some of the valleys tributary to it above Silverton. The moraines near Durango are noted, but the difference in age between the drift on the edge of the mesa lying east of the city and that lying near Animas City but little above the level of the river seems not to have been recognized. The total length of the Animas Glacier is given as about 70 miles, average slope of upper surface 83 feet or more per mile, thickness near Silverton, 1,500 feet. Attention is also called to certain facts, viz.: (1) that striations on rock in place are relatively rare on account of the character of much of the outcropping volcanic rock; (2) that a comparatively small amount of morainal material is to be found; and (3) that the amount of outwash gravels in the form of terraces and valley train is large.

1899. George H. Stone.—In *Monograph 34, U.S. Geological Survey*, pp. 340–45, Mr. Stone repeats substantially what was published in the *Journal of Geology* in 1893 in regard to glacial phenomena in the valley of the Las Animas, and adds notes on evidences of glaciation in other valleys of the San Juan Mountains, viz., the San Miguel, Uncompahgre, and upper Rio Grande; and mentions as glaciated the upper parts of the valleys of Los Pinos, San Juan, Navajo, Chama, and other rivers of the western slopes of the mountains. Moraines, erratic bowlders, *roches moutonnées*, and outwash gravels are mentioned, and locations are given for some of the best-marked instances of such phenomena.

1899. Whitman Cross.—In the *Telluride Folio*, p. 15, Mr. Cross records evidences of glaciation as follows: (1) in the upper parts of some valleys, *roches moutonnées*, striated and polished rock in place, small lake basins, and glacial cirques; (2) at lower elevations in the principal valleys and on some ridges, glacial deposits consisting of angular and subangular bowlders, gravel, sand, and finer material, sometimes in the form of small moraines, sometimes in isolated patches scattered over the surface. The largest area of drift mapped lies east of the Lake Fork of the San Miguel River and is referred to the action of a stream of water which, at a time when the ice moving down Lake Fork was higher than the canyon walls, was believed to flow during the summer in a channel along the eastern side of the glacier to join the main fork of the San Miguel River near Keystone. Aside from a suggestion that ice from Lake Fork seemed to be present at a later date than in the main fork above Keystone, the time relations are not discussed.

1900. Arthur Coe Spencer.—In the *Twenty-first Annual Report of the United States Geological Survey*, pp. 156–59, Mr. Spencer names as evidences of glacial action in the Rico Mountains (1) certain topographic features, (2) a few instances of polished and striated bed rock, and (3) some deposits of glacial débris. He concludes that the amount of ice present was small, and that the time covered by glacial conditions in this group of mountains was short.

1905. Whitman Cross.—In the *Rico Folio*, pp. 6, 12, and 13, the evidences of glaciation named by Mr. Cross are much the same as those named by Mr. Spencer in the work last cited; there is added, however, a suggestion of two distinct glacial stages, viz.: (1) a recent stage referable to the close of the Wisconsin period, and (2) a pre-Wisconsin stage. The morainal deposits, *roches moutonnées* and striae, are referred to the former; high-level bowlder beds are classified as pre-Wisconsin in age though not necessarily glacial in origin.

1905. Whitman Cross.—In the *Needle Mountains Folio*, pp. 6, 11, and 12, evidences of glacial action are noted at numerous places. The amount of morainal drift remaining in the quadrangle is observed to be relatively very small; the extent of grooved and polished surface of bare rocks, very large. From evidences of the latter kind within the quadrangle and from other evidences in adjacent quadrangles, the conclusion is reached that when glaciation was at its maximum the "greater part of the Needle Mountains area was buried beneath a thick mantle of ice and snow, from which only the higher summits projected." Only one stage of glaciation is recognized so far as observations made in this quadrangle are concerned.

1905. Whitman Cross and Ernest Howe.—In the *Silverton Folio* numerous references are made to the evidences of glacial action at points in various parts of the quadrangle. As in the *Needle Mountains Folio,* the small amount of morainal material is noted, as well as the extensive development of cirques. The authors express the opinion that the amount of glacial erosion in the glacial epoch recognized in the Silverton quadrangle was slight.

1906. T. C. Chamberlin and R. D. Salisbury.—In Vol. III of their *Geology,* pp. 334–36, Chamberlin and Salisbury include the San Juan Mountains in the term "mountains of southwestern Colorado," and, in addition to noting the former size and the altitude of the source of the glaciers in these mountains, state that the drift is referable to two or more glacial epochs.

1906. Whitman Cross and Ernest Howe.—In a paper entitled "Glacial Phenomena of the San Juan Mountains, Colorado," published in the *Bulletin of the Geological Society of America,* XVII, 251–74, Cross and Howe cite the evidences of glaciation at various points in the San Juan Mountains as noted above, and make mention of conclusive proof of two distinct stages of glaciation obtained especially in the Uncompahgre valley in the Ouray quadrangle in the summer of 1904. The chief differences noted with respect to the drift deposits of the two stages are (1) the slight modification due to weathering and erosion in the more recent deposits; relatively great changes in both these respects in the earlier; (2) the occurrence of the older drift at a greater distance from the mountains, capping ridges, and hills which had been formed by erosion before the last stage of glaciation; and (3) stratified deposits of gravel associated closely with the older deposits at relatively high elevations, and a series of gravel terraces intermediate in position between these and the earliest valley trains of the more recent stage.

1907. Whitman Cross and Ernest Howe.—In the *Ouray Folio,* pp. 7 and 15, the authors present again substantially the same data and conclusions in regard to glaciation in the Ouray quadrangle as were included in their paper just referred to on glaciation in the San Juan Mountains.

1909. Ernest Howe.—In *Professional Paper 67, U.S. Geological Survey,* Mr. Howe refers briefly in a number of places to the evidences of glaciation in the San Juan Mountains, but records no observations not included in publications already named above.

1910. Stephen R. Capps, Jr.—In the *Journal of Geology,* XVIII, 370 and

371, Mr. Capps refers to the striking similarity between the "rock streams" found at various points in the San Juan Mountains, and the "rock glaciers" of the Nizina region in Alaska. In regard to the latter he reaches the conclusion that they "are now in motion, moving in some such way as a glacier."

1910. Whitman Cross and Allen D. Hole.—In the *Engineer Mountain Folio*, pp. 8 and 9, evidences are given leading to the conclusion that the mountains of the quadrangle were subjected to glaciation at two distinct periods separated by a long interval of time.

GLACIAL PHENOMENA OF THE QUADRANGLE

As may be seen by reference to the literature cited above on glaciation in the region, complete detailed observations on the glacial phenomena of the Telluride quadrangle have not heretofore been made. By far the most complete account of such phenomena yet published is contained in the *Telluride Folio*, already referred to; but even there little reference is made to the details beyond what is necessary in illustrating general statements; and, moreover, especial attention is called to the fact that no attempt has been made to represent on the map all the deposits of glacial débris that were recognized. The overshadowing importance at that time of a careful study of the intricate relations involved in the volcanic rocks, and the demand for an early publication of the results of such study for the benefit of the extensive mining interests of the region no doubt fully justified the omission of many of the details relating to glacial action; the striking character, however, of some of the phenomena observed, and the aid which an understanding of the relations involved promised to give in the determination of some unsettled points in Quaternary history led to a systematic examination of the glacial phenomena of the entire quadrangle, the report on which here presented constitutes, therefore, a supplement to the conclusions previously published.

The evidences of glacial action found in the Telluride quadrangle include most of the characteristic marks of the work of glaciers as found in other localities, viz.: (1) cirques, (2) striated bed rock, (3) *roches moutonnées*, (4) lakes in rock basins, (5) moraines both in the form of ridges and of broad sheets with irregular, hummocky topography including undrained depressions, (6) unassorted drift including fragmental material of all sizes from fine silt to bowlders, 18 feet in diameter, and containing representatives of the various kinds of rock present in the basins from which the drift was derived, (7) striated bowlders included in the unassorted drift, (8) streams steep in gradient flowing in valleys U-shaped in cross-section, and (9) hanging valleys. Of the evidences named above it was found that a part of that referable to classes 5, 6, and 7 represents the work of an epoch or epochs of glaciation earlier than the most recent. Some of this earlier drift occurs in or near valleys in which ice of the latest epoch was present; but some in valleys which appear not to have been subject to the action of ice of so recent a time. Furthermore, the earlier drift is in some cases found on divides between valleys instead of on the slopes or bottom as is usually the case with the more recent drift, and in many cases glaciated valleys contain drift of the most recent epoch only. In view of these facts in regard to the distribution of drift of different epochs, the detailed descriptions of glacial phenomena in different basins and valleys have been grouped as follows:

I. Phenomena in each valley referred to glacial action of the more recent epoch.

II. Phenomena referred to glacial action distinctly earlier in time.

DESCRIPTION OF AREAS GLACIATED IN THE MORE RECENT EPOCH

VALLEY OF THE SAN MIGUEL RIVER

The San Miguel River is formed by the junction of Ingram and Bridal Veil creeks about two and one-half miles east of the city of Telluride. The walls of the valley near this point are, for much of their height, bare precipices, and rise from 2,000 to 3,000 feet above the bed of the stream. The channel of Ingram Creek is a continuation in direct line of the valley of the San Miguel River; but from a point a half a mile above its junction with Bridal Veil Creek to the level of the lower part of Ingram Basin, a vertical distance of over 1,000 feet, the gradient of the stream is practically that of the slope of the walls of the valley of the San Miguel on either side, so that the steep side walls of the valley of the San Miguel virtually meet each other to the east, forming a cul-de-sac which differs from a typical cirque only in the fact that its walls are deeply notched by permanent streams (Fig. 3).

Below this cirquelike valley head the height of the walls and the steepness of their slopes gradually diminish until, just above Keystone six miles to the westward where deposits in the form of moraines are abundant, the height of the walls is not more than 400 to 600 feet with a slope not steeper, in general, than 30 to 40 degrees. This comparatively low elevation of the top of the valley walls above the stream as shown just east of Keystone is due in part to the fact that the San Miguel River at this point has its channel in glacial drift, or in the silt of a lacustrine deposit which fills the channel cut in the underlying bed rock to a depth of probably 400 feet. From the morainal deposits in the vicinity of Keystone to the terminus of the glaciated area near the mouth of

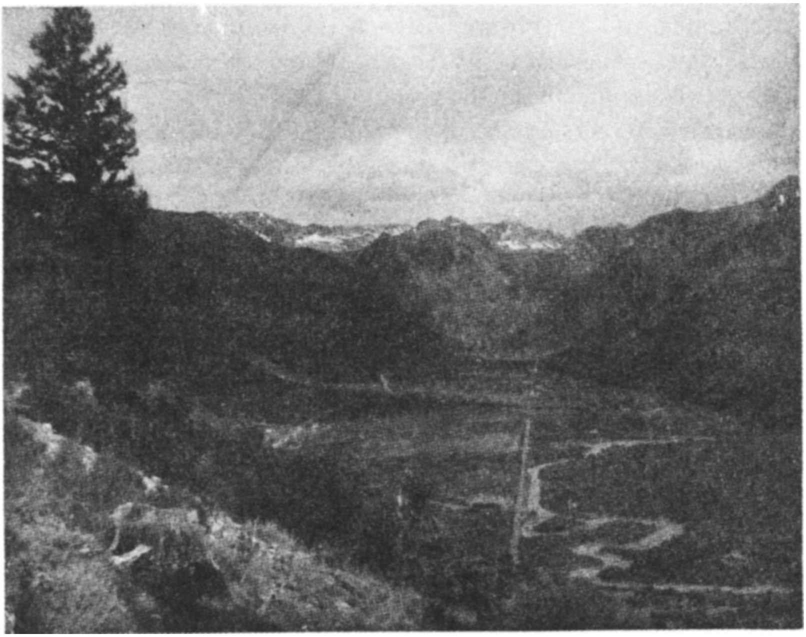

FIG. 3.—Valley of the San Miguel River, elevation 9,000 feet; looking south of east from north side of valley. Note the flat bottom, the meandering stream, and the abrupt termination of the valley in the center of the view.

Deep Creek, the valley of the San Miguel is a canyon with precipitous walls 1,000 feet high. Beyond the mouth of Deep Creek the canyon gradually increases in depth until, at Sawpit, at the northwest corner of the quadrangle, the stream is 1,700 feet below the level of the edge of the plateau in which it has cut its channel.

Drift in the valley of the San Miguel.—Drift in the form of valley train is found up to 100 feet above the stream at various points as at Newmire and Sawpit, and beyond the boundaries of the quadrangle; but the lowest point reached by the ice in the more recent stage of glaciation is near the mouth of Deep Creek. At this point the north wall of the valley is precipitous, its south wall worn and weathered until, although still steep, it has become a long, retreating slope instead of a precipice. On the north side of the river here and for about one and one-fourth miles to the eastward, no glacial débris is discernible such as could be classed as morainal. The bare cliff faces afford no place for its lodgment; and even if once left on the more level area beside the stream, it has been either washed away or covered by irregular heaps of talus which have fallen since the ice withdrew.

On the south side, however, the longer, less steep canyon wall has allowed the glacial débris to remain in sufficient quantity to mark the approximate position of the edge of the ice at the time of its farthest advance. The débris consists of bowlders in variety, some with characteristic glacial striae, exposed at various points along the boundary as mapped and to the east of this line. In sharp contrast, the slope to the west of the boundary is covered by black soil, usually with few rock fragments, or, where they exist, consisting almost entirely of fragments of bed rock.

Between Bilk Creek and Lake Fork the south wall of the canyon becomes somewhat steeper; in the upper 200 or 300 feet, however, the slope affords lodgment for drift, forming a well-marked narrow shelf for a distance of more than a fourth of a mile. The top of the mesa to the south is entirely covered with drift to a depth which at its maximum may reach 200 or 300 feet. On the north side of the canyon, the wall is still precipitous, with no possibility for the lodgment of drift; but at a point opposite the railroad bridge over the San Miguel River, drift appears on the edge of the mesa at an elevation of 9,000 feet, or about 1,000 feet above the stream. This drift consists of a narrow, thin sheet of glacial débris, with bowlders of granite and diorite-monzonite, some of them striated, mingled with a much larger number of sandstone bowlders and fragments which cannot be distinguished from the Dakota sandstone, which here forms the bed rock. Opposite the mouth of Lake Fork the drift is found farther north, covering an area which suggests a lobelike expansion of the border of the ice up the valley of the small tributary which enters from the north, and over the low divide northwestward into the upper part of the valley of a tributary of Deep Creek. At the point on the eastern side of the lobelike expansion, where the boundary of the drift returns to the edge of the canyon, a well-marked morainal ridge occurs. It has a length of about 20 rods, a height in some places of as much as 30 feet, and contains bowlders in variety up to five feet in diameter, some of them showing striations. Eastward from this morainal ridge the boundary of the drift leaves the top of the mesa, descending rapidly some 300 feet over the still steep canyon wall toward the conspicuous moraines which partially fill the valley of the San Miguel in the vicinity of Keystone.

The moraines below Keystone are formed from material brought partly by ice advancing down Lake Fork, partly by that coming down the main valley from the east. San Juan bowlders up to 15 feet or more in diameter characterize the drift from the east; granite or diorite-monzonite in bowlders up to about 3 feet in diameter, that from the south. The mesa lying in the angle between the main valley and Lake Fork is covered with drift brought from the south; this drift extends eastward more than half a mile from the nearly perpendicular rock face which at this point forms the upper part of the east wall of the canyon of Lake Fork. While there is more or less commingling of drift from the two sources, yet, speaking generally, the small tributary of the San Miguel River, which enters from the south about one mile east of Lake Fork is the dividing line between drift from the east and from the south. Half a mile west of this tributary and between the railroad and the San Miguel River, the moraines take the form of low ridges extending in a northeast-southwesterly direction. On the north side of the river, and extending one-fourth to one-half a mile up the valley from this point, are glacial deposits which are being treated by hydraulic process to recover the gold they contain. These deposits, as well as those extending eastward for half a mile from the small tributary referred to, and lying chiefly on the south side of the river, show in places layers of stratified silt, sand, and gravel; the greater part of the deposit, however, is unstratified.

The drift in the vicinity of Keystone constitutes by far the largest accumulation of glacial débris to be found in the canyon of the San Miguel; judging from the comparatively small number of large San Juan bowlders found farther down the canyon, the Keystone drift is in the nature of a terminal moraine for the glacier which advanced from the east. On August 1, 1904, drift in the form of a ridge transverse to the stream at a point about four-fifths of a mile east of the mouth of Lake Fork was being washed down in the process of hydraulic mining; the work showed that the pre-glacial channel of the San Miguel River at this point was about 100 yards farther north than at present, and approximately parallel to its present course, and that the pre-glacial channel had a depth of bed as much as 30 feet lower than the bottom of the present channel. It appears, therefore, that the pre-glacial channel was filled to such an extent as to displace the stream and cause it to flow at a higher level along the south wall of the valley where it has in post-glacial time eroded a new channel not more than 10 to 20 feet in depth.

This accumulation of drift in the vicinity of Keystone is believed to have been chiefly responsible for the existence of a glacial lake which extended eastward from Keystone to a point beyond the city of Telluride, a distance of more than four miles; and as the greater part of this drift for a quarter of a mile or more below the mouth of Remine Creek contains numerous large San Juan bowlders, the drift chiefly responsible for the existence of the lake must have been brought by glaciers from the east. The date of this glacial lake is therefore fixed for the time just following the retreat of the ice up the San Miguel valley after depositing the drift at and below the mouth of Remine Creek. The silting-up of this lake has produced a flat-bottomed, comparatively level valley, as shown in Fig. 3. The surface of this valley is now about 400 feet higher than the bottom of the pre-glacial channel of the San Miguel River exposed in the process of hydraulic mining below Keystone as referred to above.

In addition to the drift near Keystone, deposits distinctly morainal in character occur at two other points in the bottom of the valley. One of these points is between one-fourth and one-half a mile eastward from the mouth of Remine Creek; the other, just east of Eder Creek. Both of these accumulations are to be regarded as small recessional moraines. The westernmost one consists of almost bare, rounded hillocks about 60 feet higher than the level valley floor to the east, and with slopes of 25° or 30°; these hillocks constitute a narrow, but irregular belt across the valley somewhat convex downstream. The drift here consists of bowlders up to 6 feet in diameter, some of which are well striated, mingled with sand and clay. The varieties of rock present include Telluride conglomerate, quartzite and granite such as are contained in the Telluride conglomerate, sandstone both light-colored and red, and bowlders of the San Juan formation. Between this belt and the much higher, forest-covered morainal accumulation lying farther west than the mouth of Remine Creek, there is a depressed area occupied in part by ponds due to dams constructed by the Keystone Hydraulic Mining Company (Fig. 4). The second recessional moraine lying just east of Eder Creek consists of a much narrower, broken series of hillocks, likewise convex downstream. These hillocks are not more than 10 to 20 feet higher than the general level of the valley bottom. Like the first recessional moraine described, this one has bowlders in variety; but here, with the exception of San Juan bowlders up to 10 feet in diameter, they are small.

Lateral moraines along the San Miguel valley—south side.—From the low recessional moraine which lies east of the mouth of Remine Creek, a ridge of glacial drift extends eastward on the south side of the valley to Prospect Creek, a distance of half a mile. This ridge has an elevation of about 70 feet above the surface of the lacustrine plain forming the bottom of the valley, a height of crest above the depression to the south of not more than 20 feet at any point, and a width of from 10 to 150 feet. This ridge constitutes the only well-marked lateral moraine belonging to the late recessional stages of ice in the San Miguel valley.

Well-marked ridges or benches of glacial material corresponding in elevation to the upper parts of the drift accumulation near Keystone occur on the south side of the valley as follows:

1. Near Telluride, three-quarters of a mile west of Bear Creek. A small stream here enters the valley of the San Miguel from the south, and the moraine lies at an elevation of 9,750 feet across the mouth of the basin drained by this stream. The moraine is here a well-marked ridge, and stands 30 to 40 feet higher than the surface of the basin just back of it. In composition the ridge is made up of a variety of rocks: San Juan, Telluride conglomerate, light-colored sandstone, and an occasional piece of Dolores sandstone. Striated bowlders were found at the point where the stream has cut through the moraine. The total length of the well-marked ridge is something less than 80 rods. An effort was made a few years ago

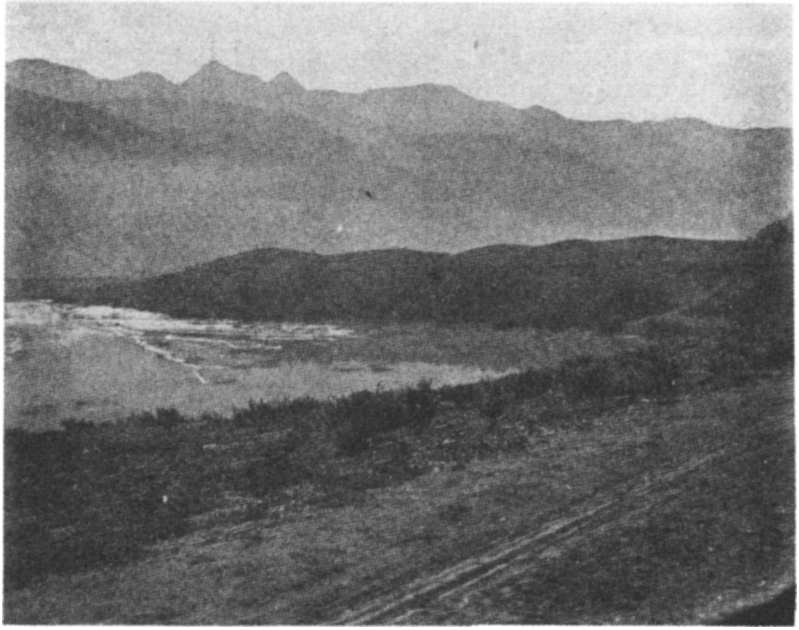

FIG. 4.—Recessional moraine (in center), in the valley of the San Miguel River about a half-mile east of the mouth of Remine Creek. Water in depression to left is held by a dam. Elevation about 8,600 feet.

to make a reservoir of the basin lying back of this ridge by filling up the stream-cut in the moraine; the dam thus formed has been largely washed away, but the name, the "Van Atta dam," is still used to refer to the part remaining. Below the moraine to the north, are two or three secondary ridges or benches, the one most plainly marked being about 250 feet below the principal ridge, that is, at an elevation of about 9,500 feet. From these ridges glacial drift covers the valley slope down to the river, nearly 1,000 feet below; bowlders up to 8 feet in diameter occur here.

2. A half-mile farther west another small tributary enters the San Miguel River from the south. The moraine here is not a well-marked ridge, but a level bench across the valley, showing sections of typical morainal débris.

3. From the point just named westward the moraine cannot be distinguished for about a mile and a half. The slope of the valley is steep, covered with a forest of spruce and aspen, and shows occasional outcrops of rock in place; little glacial débris could remain on this slope. But at a point about one-fourth of a mile east of the road which leads from the village of San Miguel up the south slope of the San Miguel valley, glacial drift appears in abundance at an elevation of about 9,550 feet on the crest of the ridge which divides the San Miguel valley from the valley of Prospect Creek, and continues as a well-marked ridge from this point westward to the deposits near Keystone. At the point where the road mentioned above crosses this ridge there is a notch some 50 feet or more in depth. Small, but distinct ridges of clay, gravel, and small bowlders lead off from the vicinity of this notch in a southwesterly direction toward the valley of a tributary of Prospect Creek. West of the notch referred to for half a mile or more the moraine consists of two distinct ridges or crests; the crests are never far apart, making thus a single ridge with a double crest rather than two separate ridges. The lower crest is always to the north, being from 50 to 100 feet lower than the other.

Through this double-crested lateral moraine Prospect Creek has cut a channel sufficiently deep to allow its basin to be drained, though it still lacks over 350 feet of having cut down to the level of the San Miguel River. The sides of the cut are steep where the stream crosses the lower ridge of the moraine, exposing unassorted glacial drift with bowlders in variety, ranging in size for the San Juan bowlders up to nearly 20 feet in diameter; the depth of the cut is here about 50 feet. Where the stream crosses the higher ridge of the moraine the cut is comparatively broad, and about 150 feet deep. The area south of the moraine at this point shows some effects of ponded waters; the topography, however, is not such as is due to the silting-up of a lake; it is rather that of a flood-plain which has been somewhat eroded.

West of Prospect Creek gap the topography is not so simple as to the east. The lower ridge persists, but the higher one flattens out southward into a series of gentle swells, and finally joins a higher point west of the road which leads from Keystone up to the plateau to the southeast. This arrangement of the drift, together with the sharp turn that Prospect Creek makes to the northward just at the gap, indicates that the valley of Prospect Creek extended on to the northwest in pre-glacial time, joining the valley of the San Miguel River probably somewhere near Keystone.

Lateral moraines along the San Miguel valley—north side.—The most easterly point at which the lateral moraine is to be found on the north side of the valley is on the west side of Royal Gulch at an elevation of about 10,000 feet. The cut made by the road at this point has exposed a heterogeneous mixture of clay and bowlders, the latter chiefly from the San Juan and Telluride formations; some of the bowlders are striated. The amount of this deposit is comparatively small; that part deserving mention as decidedly morainic is included within a distance of less than 40 rods along the side of the valley.

Farther west, a short ridge of glacial drift occurs on the east side of Cornet Creek at an elevation of 9,800 feet, and on the east side of Butcher Creek at 9,650 feet, extending in each case from the eastern side of the valley to the stream channel, and rising 50 to 60 feet higher than the somewhat flattened area just to the north.

At the junction of the valley of Mill Creek with the San Miguel, no morainic ridge appears such as is found in the valleys of Cornet Creek and Butcher Creek. The ice from Mill Creek basin evidently had sufficient force to push out into the valley of the San

Miguel any débris which the glacier in the latter may have carried at its margin. On the west side of Mill Creek a morainic ridge extends in a direction south of west from an elevation of 9,500 feet down to about 9,100 feet; but this ridge is probably chiefly due to ice from Mill Creek rather than to that coming down the San Miguel valley.

No further remnants of a lateral moraine occur on the north side of the San Miguel valley until a point is reached about three-fourths of a mile east of Remine Creek at an elevation of 9,500 feet; beginning here, glacial débris forms the top of the ridge extending south of west to Remine Creek. At its eastern end this ridge is not so well marked as the moraine on the south side of the valley; farther west the ridge is more pronounced. One noticeable feature of this part of the moraine is the number of large bowlders which lie upon its southern slope. The elevation of the east end of this ridge, 9,500 feet, is about 300 feet higher than the crest of the lateral moraine on the opposite side of the San Miguel valley. This difference in elevation is probably the result of the change in direction of the course of the valley of the San Miguel. It will be noticed that at a point about halfway between Eder Creek and Remine Creek, the San Miguel River changes its course from north of west to south of west, a change of about 25°. The ice having motion in a north-of-west direction before reaching this point would not change its direction of movement readily, and so would crowd up on the north side just below the point in the valley where the change of course takes place.

Striae and striated bowlders in the San Miguel valley.—Striated bowlders occur in abundance in the drift in the San Miguel valley, both in the moraines near Keystone, and at practically all points farther east where there is any considerable accumulation of glacial débris.

Striae on rock in place were observed at three different locations, all on the north side of the valley; in each place a part of the striae are on a rock face of steep slope, and show dip in an upstream direction. This upstream dip is interpreted as being the result of the crowding-up of the glacier on the north side of the valley, due to the force of the ice entering from two southern tributaries, viz., Bear Creek and Bridal Veil Creek. The points observed and the measurements made are as follows:

1. At several points near the Old Smuggler Mill, near Marshall Creek. In one area, 60 feet above the mill at an elevation of 9,300 feet, the rock face forming the side of the valley has a slope of about 40°; the striae dip up the valley (eastward) 15° to 17°. In another area, 150 feet to the west, the dip up the valley is from 3° to 5°. The direction of the striae varies from N. 52° W. to S. 88° W.

2. One-fourth of a mile east of Owl Gulch at an elevation of 9,400 feet (500 feet above the bottom of the valley), sandstone forming the side of the valley has a slope of face of 60°; striae dip up the valley (eastward) 10°. Direction of striae about N. 87° W.

3. About one-fourth of a mile east of Owl Gulch at an elevation of 9,000 feet, a small reservoir has been constructed with a ledge of red sandstone for its bottom. At some places the sandstone exposes nearly vertical faces, and on such faces some of the striae have a dip up the valley of about 5°. Some of the striae on these faces have an equal or greater degree of dip down the valley; but there are a greater number of striae exposed which dip up the valley than down the valley. Striae here vary in direction from S. 63° W. to N. 78° W.

Thickness of glacial ice in the San Miguel valley.—In the cirque-like head of the San Miguel valley, two miles east of Telluride, the ice was probably not less than 1,500 feet in maximum thickness. In the neighborhood of Telluride, the maximum was about 1,000 feet, the thickness gradually decreasing westward to the neighborhood of Keystone.

VALLEY OF EDER CREEK

Ice of the more recent epoch filled the main valley of Eder Creek and extended to the edge of the glacier which moved down the valley of the San Miguel. The head of the valley is an excellent example of a glacial cirque. At the sides and head are long talus slopes with precipitous rock walls in places above them; on the bottom the talus fragments have been pushed into the successive ridges characteristic of rock streams.

A precipitous rock face at an elevation between 10,500 and

11,000 feet separates the cirque from the forest-covered portion of the valley below. Below the precipice, well-developed lateral moraines extend on either side of the valley down to about 10,000 feet in elevation.. Below this point to the edge of the valley of the San Miguel, a distance of nearly a mile, the morainal deposits consist of an irregular grouping of hillocks, with a few fragments of ridges transverse to the valley. From the abundance of the moraines in the lower part of the valley, and from their arrangement partly as ground moraine and partly as recessional moraines, it seems probable that but little ice from the valley of Eder Creek was added to the glacier in the San Miguel valley.

In the valley of the east fork of Eder Creek, a glacier less than a mile in length existed in the later stage of glaciation. Above 11,000 feet in elevation the valley shows the rounded forms due to the effect of passing ice wherever rock in place outcrops in projecting ledges or points; back of the more level, rounded slopes are the precipitous faces of the bounding walls, with steep talus slopes, overgrown, in this valley, for the most part with scanty vegetation. Between 10,500 and 11,000 feet in elevation, the stream draining this tributary valley has a very steep-walled, V-shaped channel. In the bottom of the channel, and at some places for 10 feet to 20 feet up the sides, the Telluride formation outcrops; lying on the Telluride formation is glacial débris 30 to 40 feet thick, containing bowlders up to 4 feet in diameter, some of which are well striated.

The thickness of the ice in the valley of Eder Creek does not seem to have exceeded a maximum of 200 to 300 feet.

VALLEY OF MILL CREEK

The main valley of Mill Creek, heading south of Gilpin Peak, is broadly U-shaped above about 10,500 feet in elevation, becoming broader toward the upper end. Knobs of rock in place at frequent intervals show the rounded surfaces of *roches moutonnées*, but in most places no striae could be found. The surface is weathered rough, or broken up, as if by changes of temperature, into small fragments. Grooves are found at about 11,100 feet elevation on the left bank of the stream, with direction S. 43° W. In the bottom of the valley some areas are almost flat; at a few points in the upper part small ponds occur. Two rock streams occur at from 12,000 to 12,500 feet in elevation. Talus slopes and precipitous cliffs beyond the talus mark the boundary of the cirquelike valley.

The tributary valley from the northwest has a bottom with rounded ledges; but the stream is in a deep canyon part of the way, first at a point more than halfway up the valley and again near its mouth. No striated rock surfaces were observed. In general, the slope of the bottom of the valley is very steep, and the sides are made up of long talus slopes with precipitous faces above them. At the upper end of the valley is an unusually fine example of a rock stream, which extends more than a quarter of a mile from the precipice which forms the head of the valley. In the lower part of the valley of this tributary on the west side, at an elevation of about 11,200 feet, is a small area of uneven, hummocky ground inclosing a pond 30 or 40 feet in diameter; this uneven topography is evidently due to landsliding.

At an elevation of about 10,300 feet, a precipitous cliff of the Telluride formation causes falls 100 feet or more in height in the streams both from the head of the main valley and from the branch coming from the northwest. Below the falls and down to about 9,900 feet in elevation there is much fragmental material in the stream bed, rock in place being visible only occasionally. At about 9,900 feet, the stream bed lies in a canyon cut in Dakota sandstone. Again at from 9,200 to 9,400 feet in elevation there are many bowlders along the stream. At most other places, the stream has its channel in bed rock or nearly so.

Park Basin is very similar in its main features to the valley tributary to Mill Creek from the northwest. It has a steep gradient where it joins the main valley, a grade less steep from 11,000 to 12,000 feet in elevation, steep talus slopes, and precipitous cliffs beyond the talus.

On the west side of the main stream at an elevation of from 10,000 to 10,200 feet, is an area of irregular, hummocky topography, in which are some small undrained basins. The material here is clay, with pebbles and bowlders, some of which are rounded. This area clearly lies within the limits of glaciation for this valley, but the uneven topography is no doubt due largely to landsliding.

On the west side of Mill Creek where it joins the valley of the San Miguel, a short, well-defined ridge extends south of west nearly to Eder Creek. Near its upper end its crest is about 500 feet above the bed of the stream (Mill Creek), and rapidly decreases in elevation toward the southwest. On the side of this ridge away from Mill Creek its slope is short, and joins, in its upper part, the unglaciated slope of the ridge lying between Mill Creek and Eder Creek; farther down it joins the glacial débris of the main (San Miguel) valley. No ridges transverse to Mill Creek appear in connection with the lateral moraine; either no terminal moraine was formed by the glacier occupying the valley of Mill Creek, or, if formed, it has been carried away.

Upstream from the lateral moraine just referred to, one-fourth to one-half a mile from where Mill Creek enters the San Miguel valley, there is an accumulation of glacial débris lying near the stream and up to about 9,400 feet in elevation. This accumulation forms what appears when viewed from the upstream side to be an irregular, narrow terrace whose top is not more than 100 to 150 feet above stream. Above the accumulation, the valley becomes slightly broader and for about one-fourth of a mile is sufficiently level to indicate that ponding of water with accompanying silting-up must have taken place. This more level surface is in sharp contrast with the steep slope on the same side of the stream near the San Miguel valley. On the east side of Mill Creek, no terrace appears corresponding to that on the west; some glacial débris is present, however. This deposit of drift at 9,300 to 9,400 feet in elevation is interpreted as a recessional moraine which for a time partially dammed the stream.

The maximum thickness of ice in the valley of Mill Creek was probably from 500 to 800 feet.

VALLEY OF CORNET CREEK

The head of this valley is a cirque with precipitous walls, steep talus slopes, a bottom showing some rock in place, some loose bowlders, and some finer fragmental material which in places supports a sufficient growth of low plants to conceal the rock fragments under a covering of green. The tributary valley from the east, lying southwest of Mendota Peak, has much talus, a larger proportion of its area supporting vegetation, and lacks the high steep walls at its head which are characteristic of a typical cirque.

From timber line, about 11,000 feet in elevation, down to 10,200 feet, a considerable growth of trees, with the accompanying products of vegetable decay covering the ground, obscures the underlying rock in many places; a number of outcrops were found, however, yet no striae were seen.

On the east side of the valley, beginning at an elevation of about 10,200 feet and extending in a southerly direction for about one-fourth of a mile, is a distinct ridge composed, so far as could be observed, of clay, pebbles, and rounded bowlders, some of which are striated. This ridge begins just below a well-rounded ledge of the Telluride formation, and extends to the stream which joins Cornet Creek from the east on the 9,800-foot contour line.

The moraine lying across the lower part of the valley and forming part of the lateral moraine on the north side of the San Miguel valley has already been referred to. North of this moraine for nearly a mile the bottom of the valley has in most places a covering of glacial drift, part of which is stratified and part unstratified. On the west side of Cornet Creek opposite the moraine at 9,800 feet elevation, bowlders and other glacial débris lie as much as 100 feet higher than the top of the moraine on the east side. This fact probably has its explanation in the crowding-up of the glacier on the west side of Cornet Creek due to the ice coming from the valley of Bear Creek, a tributary which enters the San Miguel valley from the south at a point nearly a mile farther upstream than the valley of Cornet Creek.

The general shape of the different parts of the valley is typical of that usually found in the small, high, glaciated valleys of this region; that is, an upper portion comparatively broad and flat-bottomed, bounded by talus slopes and precipitous cliffs, and a lower part, narrower, with steep sides, gradually changing in shape of cross-section from U-shaped to V-shaped, as the tributary approaches the main stream. The maximum thickness of ice in the valley probably did not exceed 500 feet.

VALLEY OF MARSHALL CREEK

Marshall Creek drains Marshall basin and Middle basin, lying in the Telluride quadrangle, and Savage basin lying for the most part in the Silverton quadrangle. All these basins, as well as the valley of Marshall Creek below, are practically free from glacial dêbris; except for accumulations of talus and rock streams, rock in place is everywhere at the surface. *Roches moutonnées* occur at many points, and striae are abundant, their direction coinciding in general with the direction of the stream courses. Special illustrations of *roches moutonnées* may be mentioned as follows:

1. In the northwest part of Marshall basin, beginning at an elevation of 12,400 feet and including an area one-fourth of a mile square below that elevation, many *roches moutonnées* occur; striae within this area have directions varying from S. 25° E. to S. 35° E.
2. At an elevation of 11,300 feet on the north side of the road near the turn from northwest to west, two sets of striae are plainly marked; one set has direction S. 5° to 10° W.; the other set, not so deeply cut, about S. 45° W.

In the upper part of the basin the western slope is covered by a long talus slope, completely concealing the rock in place on that side. In the northeast part, at an elevation of from 12,500 to 12,800 feet, is a small rock stream.

In Middle basin a shallow lake occupies a rock basin; the outflowing stream passes through a channel about 10 feet deep. Northwest of the lake a ledge of rock in place 100 feet high shows *roches moutonnées*, but no striae. A little higher, at an elevation of nearly 11,700 feet, in both the east and the west branches of Middle basin rock streams are found extending from the base of the talus slopes which lie at the foot of the precipitous bounding walls of the valley. These rock streams are of two periods; the more recent are composed of fragments fresh in appearance, angular, and bare except for lichens on some of the surfaces. The older lie at the lower or outer edge of the more recent, the rock fragments are much disintegrated, so that the crests of the ridges are less sharp, and soil enough has accumulated to support vegetation, making the surface appearance that of rounded, green hills instead of bare ridges of angular fragments.

In Savage basin above 12,000 feet in elevation, there are found usually rock streams, and talus slopes at the bases of the precipitous bounding walls; below this elevation, as in the case of Marshall and Middle basins, there is usually a rock floor with *roches moutonnées* and numerous striae; unlike Marshall basin, however, Savage basin has a number of small rock basins, some of which contain water. The rock streams here are of two periods, as is the case in Middle basin, and the arrangement of the two with respect to each other is likewise for the most part the same, that is, the older lying as a narrow belt outside or below the more recent. In a few places, however, the older, more rounded slopes are farther up the valley than those made up of bare, angular rock fragments; this seems to be due to the movement of the fragments transported in more recent time around the older deposit, much in the way that a glacier is seen to move around an island or a promontory of rock which is a little too large to be overridden.

The maximum thickness of ice for the area drained by Marshall Creek was probably about 800 feet.

VALLEY OF INGRAM CREEK

The greater part of the area drained by Ingram Creek lies in the Silverton quadrangle. The north branch of the basin has but few good examples of *roches moutonnées*, though many projecting points and ledges are distinctly rounded. Striae bearing S. 88° W. occur on the east side of the stream at an elevation of 12,000 feet. In the upper part of the north branch are the usual precipitous bounding walls, talus slopes, and rock streams of two different periods.

The central subdivision of the basin is deeply carved. Channels up to 100 feet wide and 50 feet deep occur in the bed rock, approximately parallel to the length of the valley; the sides of these channels are precipitous, and in many places well smoothed. Striae in general parallel to the course of the stream are abundant. Talus slopes are found at the north side and the east end.

The south branch has many *roches moutonnées;* some of the surfaces are striated, some are weathered rough. Ice passed over the 12,400-foot ridge situated between the central and south branches of the basin. In the southeast part of the south branch the *roches moutonnées* forming the bottom of the basin are not more than 300 feet lower than the steep-sided ridge which forms the divide between Ingram basin and Mineral basin; it is therefore believed that the upper surface of the glaciers occupying these two basins was continuous at the time of the maximum extent of ice in the more recent epoch of glaciation.

The lower part of the course of Ingram Creek as named on the Telluride topographic sheet is an extension of the upper part of the valley of the San Miguel River. From about 11,000 feet in elevation, the stream descends in a series of falls and cataracts to its junction with Bridal Veil Creek, a total fall of over 1,500 feet in about seven-tenths of a mile. Immediately above elevation 11,000 feet, the valley has the U-shaped cross-section. At a higher elevation it assumes the form common to the high glaciated valleys in this region. The maximum thickness of ice in this valley was probably about 500 feet.